Summary of Research

NASA-Ames Cooperative Agreement Number NCC 2-1113

Investigation of Dynamic and Physical Processes in the Upper Troposphere and Lower Stratosphere

For the period April 1, 1999 through July 31, 2002

Submitted to

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Scientific Goals

The overall scientific motivation for this research has been to understand the impact of human activities on the chemistry in the lowermost stratosphere. Four research topics were investigated: 1) mechanisms that transport of air from troposphere to stratosphere and within the stratosphere, 2) the effects of clouds processes on the vertical distribution of water vapor and other trace species in the lowermost stratosphere, 3) the impact of clouds on the NO_X chemistry within these transport regimes and 4) the effects of aircraft emissions on these dynamical and chemical processes.

Introduction

Research under this Cooperative Agreement has been funded by several NASA Earth Science programs: the Atmospheric Effects of Radiation Program (AEAP), the Upper Atmospheric Research Program (UARP), and most recently the Atmospheric Chemistry and Modeling Assessment Program (ACMAP). The purpose of the AEAP was to understand the impact of the present and future fleets of conventional jet traffic on the upper troposphere and lower stratosphere, while complementary airborne observations under UARP seek to understand the complex interactions of dynamical and chemical processes that affect the ozone layer. The ACMAP is a more general program of modeling and data analysis in the general area of atmospheric chemistry and dynamics, and the Radiation Sciences program

Significant Findings

The research topics listed above were addressed in several different research tasks which are discussed below:

Analysis of thin tropopause cirrus over the central equatorial Pacific Ocean – The PI collaborated with Dr. Leonhard Pfister of the NASA-Ames Research Center in an investigation of thin cirrus observed by the Langley Research Center airborne DIAL system on flights over the equatorial zone south of Hawaii in late 1995 and early 1996. Two types of thin cirrus were identified: the first were in sheets of relatively uniform thickness and appeared to be the result of slow ascent of nearly-saturated air as it flowed equatorward from the anticyclonic side of the subtropical jet in the winter hemisphere. The second type was blobbier in structure and could usually be traced back to a relatively nearby convective event a two-to-three days earlier.

Genesis of upper tropospheric thin cirrus – The PI's work under the ACMAP has been to use convective influence analysis to determine the origins of upper tropospheric cirrus observed with the Langley DIAL on the DC-8 during four deployments of the Global Tropospheric Experiment (GTE) Pacific Exploratory Mission (PEM). Initial results indicate that most of the thin cirrus observed in the tropical tropopause layer over the Pacific Ocean can be traced back to deep convective events.

Origins of methyl nitrate in the mid-troposphere - A major finding under research topic 2 emerged from the NASA ACCENT (Atmospheric Chemistry of Combustion Emissions Near the Tropopause) airborne campaigns in April 1999. The Principal Investigator applied the convective influence technique to the problem of identifying the location and time of the source of elevated levels of methyl nitrate that were observed on two flights in the April 1999 campaign. This technique uses isentropic trajectories to identify the most likely convective events upstream from which a given set of parcels could have emerged. The results for both flights present a consistent picture of the methyl nitrate originating from deep convective events over the eastern tropical Pacific Ocean a few days upstream of the aircraft measurements.

Clouds and water vapor in the winter polar stratosphere – In a recent publication co-authored with Dr. Leonhard Pfister, the issue of clouds and water vapor in the vicinity of the Arctic tropopause during the 1999-2000 SAGE III Ozone Loss Validation Experiment (SOLVE) were examined. There are three major findings: first, troposphere-to-stratosphere exchange extends into the arctic stratosphere to about 13 km. Second, the potential for cloud formation in the stratosphere is highest during early spring, with about 20% of the parcels which have ozone values of 300-350 ppbv experiencing ice saturation in a given 10-day period. Third, during early spring, temperatures at the tropopause are cold enough so that 5-10 % of parcels experience relative humidities above 100%, even if the water content is as low as 5 ppmv. The implication is that during this period, dynamical processes near the arctic tropopause can dehydrate air and keep the tropopause region very dry during early spring.

Climatology of Florida convection – The phenomenology of deep convection and its relationship to tropical cirrus were studied as part of funding for the Cirrus Regional Study of Tropical Anvils and Cirrus Layers– Florida Area Cirrus Experiment (CRYSTAL-FACE). Analysis of satellite observations demonstrated a pronounced diurnal cycle in high-level cloudiness over south Florida where the CRYSTAL-FACE field mission will take place in July 2002. These observations and other meteorological investigations provided the basis of the forecasting approach used by the PI and his team during the July 2002 field mission in Key West.

Mission Support

The Principal Investigator provided meteorological and flight planning support for three airborne missions sponsored (in part) by these programs: two campaigns of the ACCENT (Atmospheric Chemistry of Combustion Emissions Near the Tropopause) in 1999 and a third in 2000, the three-part SOLVE mission in winter 1999-2000 and the CYRSTAL-FACE mission in June and July 2002.

a) *ACCENT:* During the field deployments of ACCENT in April and September 1999, the PI and his collaborators at NASA-Ames provided satellite imagery and convective influence forecast products together with interpretative support to flight planning for the NASA WB-57F based at Johnson Space Center in Houston, TX. In one significant accomplishment, the Ames group was able to forecast the location of a thin cirrus feature observed by the WB-57F over the Gulf of Mexico that had its origin in a convective system over the eastern tropical Pacific. Subsequent analysis of whole air samples from this encounter supported the origins deduced from the convective influence forecast.

b) *ACCENT tropical survey:* In September 2000, the PI and his collaborators at NASA-Ames provided satellite imagery and convective influence forecast products together with interpretative support to flight planning for the NASA WB-57F research aircraft as it flew to San Jose, Costa Rica from its base at Johnson Space Center in Houston, Texas.

c) *SOLVE:* The PI traveled to Kiruna, Sweden for each of the three SOLVE deployments. As part of their overall SOLVE science effort, the PI and the Ames team provided forecast maps via the web to support flight planning for the NASA DC-8 and ER-2 research aircraft. The SOLVE flights have provided a rich palette of opportunities to investigate research topics 1–3 above. In particular, several DC-8 flights penetrated tropopause level clouds at the edge of the lower stratospheric vortex and it is expected that these will offer excellent case studies for investigations of strat-trop exchange processes.

d) *CRYSTAL-FACE:* The PI organized meteorological support in Key West for the Cirrus Regional Study of Tropical Anvils and Cirrus Layers – Florida Area Cirrus Experiment for this six-aircraft mission in July 2002. He and the members of the met support team provided twice-daily consensus briefings to the mission scientists and the individual flight scientists.

Meeting presentations

The PI prepared a poster for the annual AEAP science team meeting held in June, 1999 in Snowmass, CO which presented results from the two 1999 ACCENT missions. The poster was entitled "Estimation of the impact of deep convection and air corridor traffic on upper tropospheric/lower stratospheric air parcels: Flight planning and forecasting for the 1999 ACCENT campaigns." The poster was presented by co-author Dr. Randy Friedl of the Jet Propulsion Laboratory.

In July 1999, the PI attended the first ACCENT science team meeting in Boulder, CO at which results from the April mission were presented.

In 2000, Dr. Selkirk attended the SOLVE international science team meeting in Palermo, Sicily, September 25-29 and presented a poster entitled "Elevated Levels Of Water Vapor In The Deep Arctic Lowermost Stratosphere During Solve Phase I." Trajectory modeling of these events was presented in a poster at the Fall 2000 meeting of the American Geophysical Union, December 15-19 in San Francisco entitled "The Lower Stratosphere Transition Zone During SOLVE and the Role of Intrusions of Tropospheric Moisture."

In 2001, Dr. Selkirk presented results from the ACCENT work at the Fall 2001 meeting of the American Geophysical Union, December 10-14 in San Francisco. The poster presentation was entitled "Identification of the source of methyl nitrate observed in the upper troposphere during the April 1999 ACCENT mission: A successful test of the convective influence technique" and was co-authored with Dr. Leonhard Pfister of the NASA-Ames Research Center and Dr. Elliot Atlas of the National Center for Atmospheric Research.

Publications

2001, Aircraft observations of thin cirrus clouds near the tropical tropopause, Pfister, L., Selkirk, H. B., Jensen, E. J., Schoeberl, M. R., Toon, O. B., Browell, E. V., Grant, W. B., Gary, B., Mahoney, M. J., Bui, T. V., Hintsa, E., *Journal of Geophysical Research* **106**, 9765-9786

2002, Water Vapor at the Arctic Tropopause, Pfister, L., Selkirk, H. B.; Jensen, E. J.; Podolske, J.; Sachse, G.; Avery, M.; Schoeberl, M., *Journal of Geophysical Research.* Accepted January, 2002.

APPENDIX

Subject Inventions Certification

There were no subject inventions required to be disclosed to NASA which resulted from this work. There were no subcontracts awarded under this Cooperative Agreement.